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A Sensor Technology Survey for a Stress Aware Trading Process

Javier Martínez Fernández, Juan Carlos Augusto, Ralf Seepold, Natividad Martínez Madrid

Abstract—The role of the global economy is fundamentally important to our daily lives. The stock markets reflect the state of the economy on a daily basis. Traders are the workers within the stock markets who deal with numbers, statistics, company analysis, news and many other factors which influence the economy in real time. However, whilst making significant decisions within their workplace, traders must also deal with their own emotions. In fact, traders have one of the most stressful professional occupations. This survey merges current knowledge about stress effects and sensor technology by reviewing, comparing, and highlighting relevant existing research and commercial products that are available on the market. This assessment is made in order to establish how sensor technology can support traders to avoid poor decision making during the trading process. The purpose of this article is: 1) to review the studies about the impact of stress on the decision making process and on biological stress parameters that are applied in sensor design; 2) to compare different ways to measure stress by using sensors currently available in the market according to basic biometric principles under trading context; and 3) to suggest new directions in the use of sensor technology in stock markets.

Index Terms—Decision making, sensors, biological stress parameters, trader.

I. INTRODUCTION

DURING the 1930's, Hans Sely, a medical student at the University of Prague, noted that a group of persons who suffered from different types of illnesses showed the following common symptoms: tiredness, loss of appetite, weight decrease and fatigue, amongst others. Mr Sely was the first to refer to the term “stress” in a biological context [1]. He later

broadened and popularized the concept to include inappropriate physiological response to any kind of demand [2]. In his terminology, *stress* refers to a condition and *stressor* to the stimulus causing it. Stress covers a wide range of phenomena, from mild irritation to drastic dysfunction that may cause severe breakdown in health. Currently, there are many definitions of stress. McGrath [3] conceptualized stress as the interaction between three elements: perceived demand, perceived ability to cope with the demand and the perception of the importance of being able to cope with the demand. According to Tepas and Price [4], stress is commonly connected to the following concepts: adaptation, anxiety, arousal, burnout, coping, exertion, exhaustion, exposure, fatigue, hardiness, mental load, repetitiveness, strain, stressors, and tension. It is well known that stress is studied in many research fields such as psychology, computer vision, physiology, behavioural science, ergonomics and human factor engineering.

In the present days of widespread global financial crisis, stock market traders have a particularly stressful profession. This makes the decision making process in the stock market increasingly difficult. Stability within the stock markets is largely an illusion and stress is a common denominator amongst traders. Decision making is somehow safe as long as the environmental conditions do not affect the trader. Pharmaceutical drugs such as Bitalin, Adderall, Vicodin and Oxycontin are currently widely used by traders in Wall Street to avoid panic moments by controlling the emotions of traders [5]. Decision making in the trading process (transactions with shares and bonuses made by traders in financial markets) is a good example of an activity where risk management in real time is important. Besides, this activity increases stress levels. Stress has a significant impact in decision making because it can undermine our capability to make safe decisions. Research on the influence of stress on decision making is not new. Kowalski et al. [6] suggest that a better understanding of individual judgment and decision making activities whilst under stress would yield a better understanding of how people reach the choices they make in emergencies. Adya et al. [7] provide experimental data to demonstrate that decision support systems can mitigate some reported psychological experiences under stress.

There are several available tools to assist traders in their daily work: real time chart tools, analysis of the companies by economic experts, and real time news. Furthermore, research has been carried out on the work of traders to assist them on a daily basis. Brown et al. [8] propose an expert system for the

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trading process in commodities futures. Wolberg [9] uses kernel regression for modelling financial markets. Keng and Quek [10] use a neuro-fuzzy model and Zhang et al. [11] test trading strategies for trading agents in artificial financial markets. Although all of this external information and indeed this research are positive and useful, nonetheless, trading inherently depends on good judgment exercised during real time decision making in the financial market. Crucially, no information is available to the trader about a major risk source in the decision making process: his/her own state-of-mind. The reader will see in this paper that a trader who is aware of his/her own stress levels can make more effective and coherent decisions. Bad decision making by a trader under highly stressful situations can bring about catastrophic consequences, not only on his/her finances or for the company that he/she works for, but also on the psychological health of the trader [12]. Hence, it is in the trader's interest to know if he/she is under stress, such that poor decisions may be avoided, or at least significantly reduced.

It is currently possible to use the sensor technology available on the commercial market to measure the trader's stress level in real time and this information can be fed back to him/her.

The purpose of this paper is to merge knowledge on stress effects and sensor technology by reviewing, comparing, and highlighting existing research and commercial products to establish how sensor technology can support traders providing information about their stress level and avoid bad decisions.

The contributions of this paper are as follows. Section II discusses the relationship between stress and the decision making process to understand how stress influences trader's decisions. Section III reviews the body biological response to stress and the kind of parameters we can measure in traders with sensor technology demonstrating how sensor technology can support traders by providing his/her stress level so as to avoid poor decisions. Section IV reviews the state-of-the-art in sensor technology that can be used to measure some associated parameters related to stress, following some basic biometric principles for trading context. Some sensors are illustrated, and a comparison subsection is presented. Reference will be made to relevant current research. Furthermore, future guidelines for sensor technology design in the context of trading are suggested. Section V summarises and concludes this paper by discussing new directions and open problems.

II. THE INFLUENCE OF STRESS IN DECISION MAKING

Traders continuously require good judgment in order to make good decisions in real time. It can be argued that decision making is the result of judgment, in other words, an action-based response.

Connelly et al. provide models of decision making [13] whilst others researches have characterized its role in information processing ([14], [15]) and as part of the larger cognitive architecture ([16], [17]). Judgment and decision making are altered under stress conditions, but precisely which elements of judgment are degraded and in what ways is less

clear. It has already been argued that stress can lead to hyper vigilance, a state of disorganized and somewhat haphazard intentional processing [18]. This state leads to degraded judgment and decision making. Several investigations have lent support to this theory about hyper vigilance ([19], [20]) finding this to be true for some decision making tasks made under the stress of perceived threat. Cognitive resource theory [21] confirms that stress can negatively impact on intelligence and decision quality.

The wider theory is that when a person is under stress, he/she considers fewer alternatives when searching for a solution to a problem [22]. Selten et al. [23] explain that when we have to make decisions, we use a toolbox of strategies and we apply the strategy with the most adaptive heuristic available. Adaptive heuristics [24] are simple behavioural rules that are directed towards payoff improvement but may be less than fully rational. The best known heuristic is "Take the Best" (TTB). In TTB, the person chooses between two alternatives, and predicts which of the two will have the higher value with regard to some currently relevant criterion [25]. Broder ([26], [27]) confirms how the TTB strategy works with traders in an artificial stock market where subjects tended to expand their strategy when the cost of gathering the additional information was perceived as low; however, in situations where the cost is high, they preferred the TTB strategy.

Stressed decision makers usually demonstrate impaired performance [28] and generate fewer alternatives in the decision process because these alternatives appear less attractive under conditions of stress [29]. Furthermore, traders make decisions in real time and the time impact factor is also crucial in stress levels because the search for alternatives is truncated by the time limitation ([30], [31]). In this regard, Baradell and Klein [32] reported that stress, perceived as time pressure, lowers self esteem. Furthermore, group settings studies show how the quality of group decisions also declines under stressful conditions that are due to time pressure [33].

The decision making of traders not only suffers from the negative influence of the time limitation. The decisions are in cascade and there is evidence that individuals tend to rely on previous responses regardless of previous response success [34]. It is for this reason that when a trader loses in one decision, this can negatively affect the next decision. Fatigue is another stress-related factor [35] to be taken into account. Soetens, Hueting, and Wauters found that fatigue degraded the decision making process [36].

It is important to recognize that traders, as other people, are affected by their own life and emotions. According to Lazarus [37] where there is stress, there are also emotions. He considers that the separation of these fields is an absurdity given their strong interdependence. In 1998 Ledoux [38] considered the influence of emotions in decision making. Further research ([39],[40]) shows that individuals with impaired emotional processing show an inability to observe social conventions, a tendency to take actions adverse to their own well-being that lead to financial or interpersonal losses, and repeated engagement in disadvantageous actions showing disregard to previous mistakes. Pixley argues that the intrinsic uncertainty associated with financial markets makes emotions such as confidence and trust an unavoidable element in corporative decision making [41]. Similarly, Mercer [42]

provides examples of how emotions might be useful in formulating better explanations of rationality in the context of allegiance formation, justice, and strategic choice. He states that cognition, in addition to emotions, can lead to errors of judgment. Dreisbach et al. [43] conclude that positive emotions increase flexibility in decision making, create a shift in heuristic use, and enhance the activation of remote associations from memory. However, negative emotions have a negative influence [44] on the decision making process.

One factor common to all stressful situations, and in particular to traders, is the relationship between stress and the professional experience. Professionals with more experience can multi-task more effectively than those with less experience [45]. Therefore, the quality of decision making depends on the experience level of the subject [46].

Having reviewed stress-related decision making literature, the reader will note that decision making has frequently been studied under simulation or laboratory environments. It is likely that the complexity of judgment and decision making forces this type of approach. But more restrictive approaches in real-world-like environments are highly desirable, in order to augment the study of decision making under more realistic settings.

It is clear from the research referred to above that decision making is degraded under stressful conditions. It is highly important to detect the moment in which the trader becomes stressed to avoid possible errors during the decision making process. The problem is that when the trader is under stress, he/she may neither be aware of being under stress nor of all of the effects of stress on the decision making process. Stress levels can be detected not only from the environment but from biometric data taken from the trader. Section III will first study how physiological parameters reflect stress and Section IV will show how sensors can measure these parameters.

III. BIOLOGICAL STRESS PARAMETERS

There are many studies about the biological effects of stress. Some biological signals are easier to measure than others, therefore our objective is to find representative signals that are easy to measure with the sensors that are available on the market. Nevertheless, we present all the main variables that are essentially related with stress levels, even though currently there are no suitable non invasive sensors to measure in real time some of these variables.

Cannon most likely identified the first human response to stress [47]. He established the relationship between the adrenaline level rise in stressful situations and the drop in adrenaline in a controlled situation. Many studies indicate that the endocrine system changes are high in relation to the stress level [49]. This theory has been substantiated by Coates and Herbert et al. [50] who found out in one experiment that cortisol level changed for London traders during risky market operations. However, usually cortisol is not measured in real time and it is usually measured by obtaining samples of saliva from the subject. Consequently, this parameter is not suitable for measuring the stress levels of traders in real time.

Another approach to get a stress measurement is given by the strong interdependence between stress and emotions. In this regard, there are several approaches on the detection of

emotions. This branch of affective computing traditionally relies on the detection of emotional states by means of four approaches: facial [52], speech [53], physiological features [54]; or a combination of these [55]. All these studies collect affective information and identify emotional states, making use of indirect measures which can be roughly classified in analytic, subjective, performance, and physiological measures [56]. Applying the emotional computing used in these studies to traders, facial and speech analysis are not suitable because, for example, it is not possible for a trader to stare at a fixed point without moving (invalidating the facial recognitions). Furthermore, it is not possible for a trader to speak on a continual basis (invalidating speech recognition). However, with the physiological measures (skin temperature, heart rate, etc.), Repin and Steenbarger [57] “find that subjects whose emotional reaction to monetary gains and losses was more intense on both the positive and negative side exhibited significantly worse trading performance.” These results provide valuable information to the traders, but they do not provide indications of the trader’s stress levels in real time. The researchers conclude that there is an emotion with a discrete value (sadness, happiness, fear, euphoria, etc...) and this would be a starting point to translate the emotion into a stress level measurement. However, in doing so, accuracy is compromised because the measurement is not obtained in real time.

Cacioppo [58] reviewed the neurophysiological stress response of the autonomic nervous system, detailing the sympathetic neural activation system and the various physiologic responses associated with the activation of this system (heart rate, blood pressure, respiratory rate, perspiration, inhibition of digestive system and sexual functions). According to [59] when an individual experiences stressful emotions, whether conscious of them or not, the functionality of the brain is severely compromised by chaotic electrical and electromagnetic signals. This phenomenon is called cortical inhibition. The signals are measured by the beat to beat variation in the heart rate, known as the heart rate variability or HRV. The inconsistent and chaotic heart rate is a reflection of cortical inhibition. In the same study, this cortical inhibition is tested in relation to the impact of stress on the cardiovascular system in real time. The more stable the frequency and shape of the waveform of the heart rate, the more coherent in physiological terms is the person. When physiological coherence occurs, the brain associates it with feelings of security and well-being but when stress appears, it provokes cortical inhibition and an unstable waveform of the heart rate, as we can see in Fig. 1 extracted from this study.

Following this line of research [60], there is a relation between heart rate variability derived from the electrocardiogram (ECG/EKG), blood pressure, and stress. Work reported in [61] describes the relationship between the changes in heart rate, blood pressure, skin temperature, and muscle tension in stressful moments. Skin conductance [62], the breathing rate [63], the brain waves [64], and the pupil diameter [65] are related to stress too. Based on these studies we can conclude that there are some main variables (called biometric variables) that change in stress situations: heart rate, blood pressure, breathing rate, brain waves, muscle tension, pupil diameter, skin conductance and temperature.

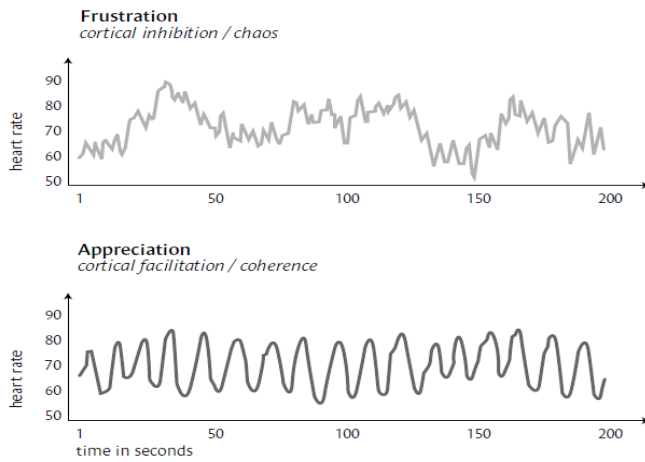


Fig.1. Different Heart Rhythms (coherence and chaos)

Finally some research addresses the measurement of stress through biometric variables (sometimes referred to as biosignals). For example Kobayash et al. [66], attempt to detect stress by using biosignals under visual search tasks. Sul et al. [67] evaluate stress reactivity and recovery with biosignals and fuzzy theory. The method of stress measurement through biosignals has indeed been applied to some aspects in natural situations such as for quantifying driver stress (see Healy et al. [68]).

Therefore, we can obtain biometric variables that change in our body and there are some sensor devices which are suitable to measure biometric data from the trader in real time. In summary, the studies discussed above illustrate that the biometrical variables which have a direct impact on stress levels are as follows:

- 1) GSR (Galvanic Skin Response): this measures the electrical conductance of the skin. The signal can be decomposed into Skin Conductance Responses (SCR), related to short events, and the Skin Conductance Level (SCL), and related to the underlying basal arousal activity. The GSR is often the primary psychophysiological measure used when gauging emotional and stress activation as it responds very quickly (1-3 seconds after onset of stimulus);
- 2) BVP (Blood Volume Pulse): is an indicator of blood flow using a photoplethysmography. In stress, the amplitude of the blood volume pulses tends to decrease following sympathetic arousal;
- 3) HR (Heart Rate): is computed from the raw BVP waveform by finding consecutive local maxima. An increase in sympathetic activity will increase the heart rate. Besides the Heart Rate Variability (HRV) and the Electrocardiogram (ECG/EKG) in stress is inconsistent (cortical inhibition);
- 4) EMG (Electromyogram): this is the electrical activity of the skeletal muscles (characterizes neuromuscular system). The greater the stress, the more likely the muscles will produce a synchronous twitching effect;
- 5) EEG (Electroencephalogram): measurement of electrical spontaneous brain activity and other brain potentials.

Stress could throw the frequency to the higher beta range brain waves;

- 6) Temp (body/skin Temperature): this is the actual temperature of the body and the skin. In stress situations the temperature of the body and skin changes;
- 7) BR (Breathing Rate): this is the number of movements which are indicative of inspiration and expiration per unit time. Under stress, this number is altered; and
- 8) EOG (Electrooculography): measurement of retinal function by recording changes in steady, resting electric potentials of the eye. Under stress, important changes in these measurements take place.

In summary, higher stress is detected with lower BVP values, higher BR, EMG, GSR, SCR, HR values and changes in TEMP, EOG, and HRV. If it is possible to measure these variables in real time, it is possible to gain an understanding of the trader's stress levels that can be fed back to the user. In the next section, a possible sensor technology support measuring these variables to improve the trader's decision making process is suggested.

IV. SENSOR TECHNOLOGY, A POSSIBLE NEXT STEP TO IMPROVE THE TRADING PROCESS

This section reviews the technology evolution in trading and discusses how sensors could improve the trader's decision making process. A sample of sensors currently available in the market is shown. They are suited to measure the necessary biosignals which can reflect the trader's stress levels. These are analyzed through basic biometric principles defined to assess them on the trading context. Usually the devices capable of measuring biosignals are also called biofeedback devices, understanding that biofeedback is the process of becoming aware of various physiological functions using instruments that provide information on the activity of those same systems, with a goal of being able to manipulate them at will [69].

This section also addresses some current research projects on this type of sensor technology, provides a comparison of the products referred to in this review based on the basic biometric principles to fit in the context of trading and discusses when sensor technology can be decisive in the trading process. Finally, this section provides guideline considerations for developers of sensors for the trading market.

A. Technology evolution in trading

In the 12th century in France, the courtiers de change were concerned with managing and regulating the debts of agricultural communities on behalf of the banks [70]. As these men also traded in debts, they could be called the first brokers. The face-to-face exchange of money and goods was replaced with technological innovations, such as the telegraph, allowing a global separation of the flow of financial information from the physical transportation of money. According to [71], this financial information was firstly printed on paper and later distributed in electronic form changing the social interaction in financial markets. From a face-to-face market we have

currently a 24-hour global market with fluctuating exchange rates and subsequent speculation [72] supported by electronic trading mechanisms ([73], [74]). This trend is continuing by replacing direct human decision-making with computer-based algorithmic trading [75].

An overarching goal during this historical process is the increase of profit. It is one of the subjects where more research and studies has been carried out. Most of these studies have focused their effort in creating systems to try to predict the movements of the financial markets and take advantage of that [76]. However, the financial markets are changing every day and in this kind of volatile scenario, systems that are effective today may not be effective tomorrow. The latest systems that are being used in the market are high-frequency trading systems [77]. These systems are based on programs running on high-speed computers that analyze market data, using algorithms to take advantage of trading opportunities that may open up for only a fraction of a second or for several hours. The more technological advances are applied to trading, the less human decision is required in real time, moving this responsibility to the programmers designing trading algorithms. The problem is that there are a lot of critical opinions to the use of that kind of systems, arguing that the volatility is growing up favouring the instability of the financial markets and the impossibility for small traders to have a chance in the market. The United States stock market crashed on May 6, 2010 [78] (called flash crash). In this day the Dow Jones Industrial Average plunged to its largest intraday point loss and this was attributed to the use of trading systems. Probably the perfect balance between a technological offer to help traders and improved human decision making allows avoiding great losses due to risky decisions. A growing body of interdisciplinary research foregrounds the activity performed within this work, in particular the constant need for collaboration between social and technical factors at the level of discourse [79]. In the next subsection it is possible to see how the sensors currently offered in the market could help in doing that.

B. Improving human decision making. A possible currently sensor trader monitoring.

The relevance of stress in the market is becoming increasingly significant, particularly during times of economic crisis when workers are under more pressure. The technical literature and the commercial products available offer devices capable of obtaining biometrical measures that could be relevant to the trading process.

For example, section III highlighted biometrical variables which can have a direct impact on stress levels. Some sensors currently available in the commercial market have the capacity to gather the information which needs to be fed back for to the trader to understand his/her stress level. We explain this technological offer in further detail below, including related current research projects using this kind of sensor technology.

The sensors will be classified according to some basic biometric sensor principles (Table I) that under our understanding are crucial in trading context. The complete list

of analysed sensors is presented in Table II. This table contains the following columns: sensor: name of the sensor; figure: a small illustration of the sensor; developer/reference: manufacturer of the sensor and a reference for further information; measured signals: the stress-related biometrical variables that can be measured by the device¹; communication capabilities: the way in which the device transmits the data; and specifications: some technical specifications and some details are shown according to the product. The acronym 'N. A.' is used to indicate that the information is not available for a particular product. For ease of reference, a lower case letter is added before the name of the sensor to reference it in the comparison table which follows in subsection B.

1) Biometric sensor principles under trading context

One of the most extended uses of biometric sensors is the identification of the user for any purpose (security, health, etc.). There are some basic biometric principles to evaluate whether a particular body (biometric) characteristic is suitable to identify a person, which are known as the seven pillars of biometric wisdom [80] (universality, distinctiveness, permanence, collectability, performance, acceptability, resistance to circumvention). However, in the trading context, we need to change the focus from identification to the characterization of the state of the user and this shift changes slightly the principles. We propose to consider the principles for biometric sensing in the trading context listed in Table I.

TABLE I
BIOMETRIC SENSING PRINCIPLES TO DETECT STRESS IN TRADING

Principles	Explanation
Universality	Stress has impact in all human beings in the same physiologic variables: blood volume pulse, breath rate, electromyogram, galvanic skin response, heart rate, temperature, electrooculography and electroencephalogram
Permanence	The anomalous values of the physiologic variables persist throughout a stress episode
Performance	A person's physiologic measure needs to be collected in a reasonably efficient way.
Accuracy	Trader's stress levels must be accurate enough to be fed back to the trader as reliable information.
Acceptability	Applications will not be successful if the trader offers strong and continuous resistance to intrusive biometrics.
Adaptability	The measures fed back to the user must be adaptable, from real time measures to more flexible and comprehensive time windows.

In Table I is possible to appreciate that the two first principles, universality and permanence, are closely related to the physiological variables that change in our body under stress influence. If we want to monitor traders, the first consideration to take into account according to the universality principle is to select a sensor capable of measuring one or several of these concrete variables suitable for any trader. Besides, according to the permanence principle the measures

¹ Some of these sensors can measure further biosignals which are not related to stress measurements and these signals are not included in the table.

should be continuous, this allows monitoring of the trader the whole time to be able to determine at what point the trader enters a stress period. We consider that the two first principles are essential and they must be fulfilled before considering the rest of the principles.

Following with the rest of the principles, according to the performance principle it is desirable to avoid delays obtaining the stress measurement. These delays can have different sources, from the limitation of the communications capabilities of the sensor to the time needed to translate the biometric measures into a stress level indicator.

Currently there are no studies indicating what kind of biometric variable measure is more precise than other to measure stress. However, the more different biometric samples we gather to get the stress measurement, the closer we are to the real perception of the stress levels. This is the reason why we have related the accuracy principle with the number of sensors that are sensing the trader. If the stress level measurement is based on one biometric variable, this measurement is less reliable than if it is based on larger array of biometric variables. The more comprehensive the measuring is, the more likely to reduce false positives. A system depending only on one parameter can be easily fooled, for example by an increase of temperature in a room or by a trader with a pacemaker.

Consistent with the acceptability principle, some sensors may be more suitable than others for the trading process. Ideally, the biometric data should be collected by the device in a non-invasive manner. We consider that this would be achieved if the trader retains sufficient physical mobility to carry out his work (most traders are situated in front of computers) and the sensor should not feel uncomfortable to the trader. Furthermore, the "invisibility" of the sensor will largely increase its acceptability.

Finally the adaptability principle deals with the capacity of the sensor, and its software, to adapt the measurements taken to the trader's profile. For example, the trader should be able to choose flexibly monitoring time periods when stress levels are predominant.

We have selected in the current commercial market some sensors available that fulfil the two first principles. In the next subsection we analyze how much the rest of the principles are fulfilled depending on the specific sensor selected.

2) Biometric sensors currently available applicable to the trading context.

Nowadays, it is possible to purchase several devices to measure individually the biosignals related to stress. Table II shows some device examples that measure one only biosignal ("a"- "h").

It is necessary to take into account that generally the communications capabilities of these sensors are limited (for example using a USB port as in "a", "c", "d", "h") or even not present ("b", "e", "g") which also has a high impact in the performance principle. In most cases the trader should pay attention continuously to the information coming from the sensor, breaking the acceptability principle. With a suitable

communication module it is possible to delegate the presentation issue to the computer.

Within these examples ("a"- "h") only one biometric measure is taken from the trader breaking the accuracy principle. This principle is completely covered with the multichannel devices. The multichannel devices ("i", "j") are devices capable of gathering the maximum number of biosignals at the same time (up to 16) whereas the rest of the sensors of the table ("k"- "u") are limited to a few (2, 3 or 4). The main difference between the multichannel devices models relates to the number of biosignals that the device can gather at the same time (number of channels). It should be taken into account that sometimes, more than one channel is needed for one biosignal. These devices usually include software to manage all data in real time. However, the stress level is not directly measured with this kind of product, so we would need to develop extra software. Besides the device requires a more complicated configuration setup in order to place the sensors on the trader, and he/she is required to carry a unit (to connect the sensors) which is not very comfortable and it is intrusive breaking the acceptability principle.

The best sensors available in the market to fulfil the acceptability principle are the wearable sensors. There are some examples that could be used by traders. Recently, Pantelopoulos and Bourbakis published a complete survey [81] about this kind of sensors for health monitoring and prognosis. The technical literature highlights high wearability and comfort for the user as advantages for devices based on smart textiles ("k", "l", "m"). Besides, when contact between the skin and the biosensors can be guaranteed, even when the subjects are in motion, increases their reliability. Also the other wearable sensors presented in Table II ("n", "o") are not invasive for the trading process. This is illustrated by Leon et al. [82] using a prototype t-shirt to determine an affect-aware behaviour model. However, as wireless technology is used in most cases ("k", "l", "n", and "o"), the sensor requires small batteries in order to be wearable which means that the trader need to check that the device have enough battery for the next trading session. Changing the batteries whilst trading would break the acceptability principle. As in previous cases, there are no wearable sensors providing the stress level measurement. However there are also sensors available in the market with this feature.

There are not many examples of sensors directly measuring the stress levels on the current commercial market. Table II provides some designs available. There is no concrete unit designed to reflect stress levels, but we can observe two main tendencies to indicate stress related information: the usage of colour ("q", "r"), and the usage of waves ("p", "s").

The primary advantage of these sensors is that it is possible to obtain a stress level measurement saving the need to develop extra software. In most of the cases ("q", "r" and "s"), this measurement is obtained in real time, which is ideal for the trading process. However, in some cases ("p", "s") the difficulties already discussed about usage of batteries and few biosignals measured remain, compromising the acceptability and accuracy principles.

Finally there are some biometric sensor prototypes (no commercial product available) that could be interesting into trading context although the stress level measurement is not available. As example two of these prototypes are shown in Table II (“*t*”, “*u*”). In the case of “*t*”, the mouse device is highly useful because most traders use computers in their work. However, the trader is required to be in constant physical contact with the mouse in order to obtain continuous feedback failing in the adaptive principle. The continuous feedback is the great advantage of the wearable EOG goggles (“*u*”) although only EOG biosignal measure is obtained, failing in the accuracy principle.

Most prototypes are the result of current research projects. In the next subsection we show how these research projects use the sensor technology in different areas.

3) Research Projects

In this subsection, the reader can find some projects where the sensor biofeedback field has an important role. The first projects presented are those where the target is not related directly to the stress measurements; they provide an idea of the focus in the current research projects with regard to biofeedback measurements. They illustrate the kind of added value the technology can offer us. This added value is also useful for our main target, the stress measurement and some examples are presented after.

- 1) The DARPA-ASSIST (Advanced Soldier Sensor Information System and Technology) program [83] enhances battlefield awareness via exploitation of soldier-collected information through a light-weight, wearable multi-sensor collection device [84]. A multi-sensor board is used with a 3-axis accelerometer, microphones, photo-transistors and barometric pressure sensors. A shooter localization technology (Vanderbilt University’s System [85]) also has been developed using 10 acoustic sensors.
- 2) The SESAME [86] consortium is a multidisciplinary group that investigates the use of wireless sensor-based systems with offline and real time processing and feedback in enhancing the performance of elite athletes. The current work includes pressure sensors in shoes (1000 samples/sec) to analyse foot contact intervals from shoe pressure and inertial sensors on limbs to measure the speed of motion from inertial and foot contact.
- 3) Healthcare@Home project [87] aims to integrate invasive and non-invasive patient monitoring systems with analysis of this information via grid infrastructure. The infrastructure promotes continuous and discontinuous (push/pull) monitoring of patients at home, employing a new class of dedicated home healthcare server relaying data from and to prototype Bluetooth sensor/comms devices. The project uses diabetes as the exemplar disease context and glucose monitoring sensors to provide real-time continuous measurements.
- 4) The WearIT@work Project [88] aims to empower the mobile worker by wearable computing and intelligent clothing. Various low-embeddable physiological sensor modules, for measuring ECG, SpO2 (pulse oximeter),

HR, aortic pressure wave, and breath-to-breath CO₂ / O₂ concentrations, are used in the project scenarios. These sensors are particularly relevant to the BSPP / Rescue scenario for a physiological monitoring of firemen.






















- 5) HeartCycle project [89] works to improve the quality of life for coronary heart disease and heart failure patients by monitoring their condition and involving them in the daily management of their disease. Some sensors used are cuff-less blood pressure, wearable SpO₂, inductive impedance, electronic acupuncture system and new sensor development like contact-less ECG, arrays of electrets foils, motion-compensation in ECG, cardiac performance monitor (bio-imped).

These research projects probe the multidisciplinary use of the biometrical measures gathered through different sensors. The trading context is not different and although currently it is not possible to find entire research projects in the area, the following examples are some studies related to the use of sensors in trading:

- 1) Lo and Repin [90] tested whether financial markets are governed by rational forces or by traders’ emotional responses. They used a ProComp+ unit (an older version of “*j*”) and gathered from traders the following biosignals: EMG, TEMP, SCR, BVP and BR. They reported that physiological/biometric variables associated with the autonomic nervous system are highly correlated with market events even for highly experienced professional traders. In this research it is possible to see how this kind of sensor breaks the acceptability principle due to the reduced mobility of the traders due to all the sensors used and the complicated set-up of the device.
- 2) We tried [91] to integrate the sensor technology into the trading process without breaking the biometric principles. In this case, we used an emwave sensor (“*q*”) to support the trader throughout daily work presenting in real-time to the traders their self-aware stress state information. Feedback to the traders improved their daily profit, by avoiding risky decision making in crucial moments of the trading process. These conclusions agreed with the previous work of Lo and Repin, but in this case the technological set up was more user friendly.
- 3) Another recent study [92] based on the conclusions of both previous works explores the consequences of the high correlation between financial markets and traders’ emotional responses. In this work we use the same analysis techniques applied in the share market in the traders’ behaviour measured with emwave sensor. From this comparison we conclude that indeed principles of market analysis are applicable to the traders’ state. This conclusion match up with both previous works about the importance of the crucial information gathered through traders’ sensor monitoring to improve the trading process.

This review illustrates the sensor technology that is currently available on the commercial market under the basic principles addressing the trading context and where the current research projects on this technology are focused, including the trading process.

TABLE II
SENSORS APPLICABLE TO STRESS-MEASURING

Sensor	Figure	Developer/ Reference	Communications Capabilities	Measured Signals	Specifications
a) Polar RS800		Polar / [93]	Polar IrDA USB	HR, HRV	Soft textile chest transmitter 2.4 GHz included
b) GSR 2		Thought Technology / [94]	N.A	GSR	Skin resistance range 1,000 ohms - 3,000,000 ohms Variable frequency range 0 to 40,000 Hz
c) HEM 790IT		Omron / [95]	Omron USB cable	BP, HR	2 User - 200 Total Memory with Date and Time Stamp
d) PS2133		Pasco/ [96]	PASPORT™ USB interface	BR	Range: 0 to 10 kPa. Accuracy: ± 0.5 kPa Maximum Sample Rate: 20 samples per second
e) SC911		Bio-Medical Instruments / [97]	N.A	TEMP	Reads in increments of 1/10 of a degree F Range: 58 to 158 degrees F. Accuracy: ± 1.8 degrees F
f) Neurobics A3		Neurobics / [98]	Wireless	EEG	Software and PC wireless receiver included. Sampling rate: 122 samples/sec. Processor: 10 bit
g) Clinical EMG		Metron / [99]	N.A	EMG	35 Segment LED Bar graphs and four LED numeric Displays. Frequency Range: 10 Hz \pm 3 Hz @ 80 dB/Dec (Butterworth) to 450 Hz \pm 40 Hz @ 40 dB/Dec (Butterworth)
h) S225		Qubit Systemsb / [100]	USB	EOG	3 electrode cables, a set of 100 disposable electrodes, and a laboratory manual are included
i) Biopac MP150		Biopac Systems / [101]	Ethernet	All (16 channels)	Power source: AC Adapter. Resolution: 16 Bits. Absolute Maximum Input: ± 15 V. Operational Input Voltage: ± 10 V. Accuracy (% of FSR): ± 0.003 .
j) Flexcomp Infiniti		Thought Technology/ [102]	USB/Bluetooth (additional device Teleinfiniti)	All (10 channels)	Power source: Batteries. Resolution: 14 Bits. Input range: $2.8V \pm 1.696V$ 2048 samples/sec on all 10 channels. Accuracy: 5%
k) Lifeshirt		Rae Systems / [103]	Wireless	HR, BR, TEMP	Meet the needs of first responders, hazardous material workers, fire fighters, industrial cleanup crews, and homeland security. A proprietary modem is used to transmit the data. Autonomy 220 hours.
l) Vital Jacket		Mind Media B.V / [104]	Bluetooth	HR, ECG	High level sport to fitness and health applications. Use three disposable electrodes that are attached via fine-wire technology. Data can be collected over 72 hours and are stored on an SD memory card or sent it. Autonomy 72 hours.
m) Smart Underpants		Joseph Wang / [105]	N.A	HR, BP	Future healthcare, sport or military applications. Use amperometric sensors through direct screen-printing onto the textile substrate. Electrochemical sensors printed on the elastic waist offers direct contact with the skin.
n) Exmocare BT2		Exmovere Holdings/ [106]	Bluetooth	HR, BVP, TEMP	Alert care providers using infrared signals to determine blood volume pulse without chest straps, electrodes or two-handed contact. Able to detect human emotional and behavioural states, including side effects to drugs. Autonomy 18 hours.
o) Emband 24		Emsense / [107]	Wireless	HR, EEG, TEMP	Designed for consumer's market research. Utilized for in-context studies such as in-store shopper research and product innovation. Using 24 EEG sensors, each measuring at 20,000 times/s, the headset collects 480,000 measurements/s.
p) Stress Monitoring		Firstbeat / [108]	N.A	HR, ECG	Power supply: Battery (Over 96 hours). Measurement accuracy 1 ms (1000 Hz). Recording capacity 1,960,000 heartbeats (app. 14 days). Real time: no. Indication: wave
q) emwave desktop		Heart Math / [109]	USB	HR, HRV	USB Plethysmographic pulse sensor for ear, optionally for finger. Sample rate 360 samples/s. Gain setting adjusts automatically via LED duty cycle and photo diode gain adjustment. Operating range 30 - 140 beats/s. Real time: yes. Indication: colours
r) Rationalizer		Philips / [110]	Wireless	GSR	Created by Philips and the bank Abn Amro. It consists of two components, the EmoBracelet and the EmoBowl. The bracelet measures the GSR and the emobowl show the properly colour indicating the stress level. Real time: yes. Indication: colours
s) Stresseraser		Helicor Inc. / [111]	N.A	HR, HRV	Power supply: Batteries. In the screen of the device is shown a wave which represents the pattern of HR. A series of triangles appear on the screen functioning as cues to modify the BR. Real time: yes. Indication: wave
t) emotional mouse		Quian Ji / [112]	USB	HR, GSR, EMG, TEMP	Developed in order to evaluate the user's emotion when the individual uses a computer. Uses behavioural information (mouse movements, button click frequency, and finger pressure) and physiological information (sensors).
u) EOG Goggles		A. Bulling ETH Zurich / [113]	Bluetooth	EOG	Use of dry electrodes. Automatic analysis and data storage. Adaptive real-time signal processing. Artefact compensation.

C. Comparisons, discussion and theoretical considerations

In this section, a comparison table is provided (see Table III) with reference to all of the sensors described above. It is possible to find comparisons about some sensors described in this paper based on their technical specifications as for example in [114]. In this case, the comparison table is based on relevant and important criteria for the trading process taking into account the principles mentioned in subsection B. It is important to point out that the purpose of this comparison is not to criticise the sensors. The main objective is to have a global idea of what kind of sensors we can find in the market and what problems arise under basic principles to apply these sensors to the trading process. This table illustrates how every sensor fits to every criterion in the following way: very good relation: “4”; good relation: “3”; bad relation: “2”; very bad relation: “1”; not applicable relation: if the criterion is not applicable to the sensor, “Na” is inserted; and if no information is available for an applicable criterion, a “?” is inserted.

The criteria used in Table III is based on the basic principles mentioned in Table I for trading, applied into the sensors shown in Table II. In order to provide a more exhaustive comparison we associate these principles in nine technical criteria referred to the technological characteristics important for trading process. This association allow us to show the impact of the current characteristics of the available technology in the basic principles. This gives us an indication of the areas to improve. Bearing in mind that the universality and permanence principles are considered achieved by all the sensors, we use these principles to select the examples illustrated in Table II. Below are described the nine criteria relating them with the basic principles in format “Criteria. Principle: Description”.

C1: data shown in real time. Adaptability principle: This indicates whether the sensor is able to send the gathered data from the human body in a period of time suitable from trading. We consider 1 measure per second enough to fulfil this criterion. It is important to traders to know all the information in real time in order to make decisions with all the updated information. A sensor receives a mark of “4” in this criterion when the sensor responds in real time and “1” if it does not;

C2: stress measurement. Performance principle: We can develop the necessary software to obtain a level of stress based on the measured parameters of the sensors. For this comparative we consider that it would imply delays due the additional execution time. It is important to know if a specific stress parameter is supplied. For this criterion, a “4” is inserted when the sensor has stress measurement and “1” if it does not;

C3: inclusion of software. Performance principle: Depending on the sensor, it may sometimes be necessary to observe the own sensor to access to the measurements implying distractions for the trader. For this criterion “4” is inserted when the software is included and “1” if it is not;

C4: data logging. Performance principle: This is a significant parameter if the trader needs to review the data and save the sessions to analyze his/her decisions. A “4” is inserted when

the sensor has data logging and “1” if it does not;

C5: wearability (visibility). Acceptability principle: In some cases this parameter could be crucial depending on the scenario for the trading process (home/ investment company/ live trading as Wall Street). A “4” is inserted when the sensor is not visible, “3” when it is visible but it is still wearable, “2” when it is not wearable but the sensor could be carried discreetly, “1” is inserted when the sensor should be fixed and it is impossible to carry;

C6: intrusive / non intrusive (comfortable). Acceptability principle: Depending on the trading scenario, it may not be necessary to have a wearable sensor; however in most cases a non invasive sensor is necessary so that the trader is not disturbed during his work. The symbol “4” is assigned when trader movements and comfort are not compromised, “3” is assigned when the trader can move freely but comfort is compromised. The symbol “2” is used when the sensor is linked with cables or comfort and movements are compromised and “1” is marked when the sensor is connected to cables and comfort and movements are compromised;

C7: accuracy. Accuracy principle: The more biosignals measured by the sensor, the greater the accuracy in calculating the stress trader's stress level measurement. In this case, the symbol “4” is used when the device gathers all of the biosignals measurements related with stress, “3” is inserted if it gathers more than two biosignals, “1” when it measures two biosignals and “1” when only it measures only one biosignal;

C8: autonomy. Acceptability principle: Traders should not need to be aware about the battery life of the sensors because they should not be distracted from the trading process. In this criterion, the symbol “4” is inserted to show that the device can be plugged into the power supply as well as having batteries. The symbol “3” is inserted when it only can be plugged into the power supply or the power supply source is through a USB port. The symbol “2” is inserted when the sensor only has batteries and we put “1” when it only as batteries and the battery life is lower than 24 hours; and

C9: communication capacities. Performance principle: The more communication capacities the sensor has, the more possibilities the trader has to include the sensor within trading process. In this case, the symbol “4” is inserted when the device has wired and wireless capabilities. The symbol “3” is inserted to indicate when the sensor only has wireless capabilities. The symbol “2” is inserted when the sensor only works with wired communication and “1” shows that the device has no communication capabilities.

To maximize the usefulness of Table III and in order to establish the most suitable sensor for the trading process, it is necessary to bear in mind that depending on the trader's profile (if he works for him/herself or for a company, if he is trading in shares, futures, commodities, risk profile, etc...) and his environment (the place where the trading process is carried out), some sensors may be more appropriate than others giving more importance to some principles than others. However, the relevance and importance of the principles will be different in each case. Some examples of different environments and profiles are as follows:

- 1) trading with shares from home: in this case, the trader works for him/herself and the environment is the home. This type of trader usually trades with a computer in a seated position. In this scenario the acceptability principle (C5, C6 and C8) would not be of crucial importance. Furthermore, in this particular case, the frequency of decision making is usually moderate and therefore it is easier to identify critical times so the accuracy principle (C7) would be of less importance. On the other hand, the performance principle (C2, C3, C4, C9) would be crucial for the user and sensors such as “q” could be appropriate;
- 2) trading in an investment company: in this case, also the trading process is done with computers and sitting so acceptability principle (C5, C6 and C8) still keeps a secondary role. However, in this case probably the company has a computing department, so it is possible that they can develop suitable software according to the traders’ needs that for example can transform biosignals measures into stress measurement so the performance principle (C2, C3, C4 and C9) could be achieved with technical support. Besides, in these companies the traders usually have a high frequency number of operations and works with many investment products at the same time, so accuracy principle (C7) could have a crucial role. In these cases sensors like “i” or “j” could be a good option;
- 3) live trading (e.g. Wall Street): it is possible to see on television, for example, how frenetic trading can become in live environments such as Wall Street. Obviously in this case, the traders are employees for investment companies and in contrast with the previous scenarios, acceptability principle (C5, C6 and C8) is the most important and sensors such as “l” or “n” are selected for this category on the basis that the relevant companies can develop the necessary software.

TABLE III
COMPARISON

Sensor	C1	C2	C3	C4	C5	C6	C7	C8	C9
a	4	1	4	4	4	4	2	2	3
b	4	1	1	1	2	3	1	2	1
c	4	1	4	4	2	1	2	4	2
d	4	1	4	4	2	1	1	?	2
e	4	1	1	1	2	2	1	2	1
f	4	1	4	4	2	2	1	2	3
g	4	1	1	1	1	1	1	3	1
h	4	1	1	1	1	1	1	?	2
i	4	1	4	4	2	1	4	3	2
j	4	1	4	4	2	1	4	2	2
k	4	1	4	4	4	4	3	2	3
l	4	1	4	4	4	4	2	2	3
m	4	1	?	?	4	4	2	?	?
n	4	1	4	4	4	4	3	1	3
o	4	1	4	4	3	4	3	?	3
p	1	4	4	4	4	4	2	2	1
q	4	4	4	4	1	2	2	3	2
r	4	4	?	?	4	4	1	?	3
s	4	4	1	1	3	3	2	2	1
t	4	1	4	?	4	4	3	3	2
u	4	1	4	?	3	2	1	3	2

There are many combinations for potential options and Table III attempts to assist traders according to his/her requirements. It provides information about different sensors that may be applied to the relevant principles. In all cases, and aside from the criteria, it is possible to identify where improvements could be made in sensors, particularly from the point of view of the technology. We consider that improvements could be made in the following areas helping to fulfil successfully the basic principles:

- 1) performance: a standardization process is required for interoperability between various types of sensors. This is raised because all of the software is proprietary and even the communication in some cases is not standard (“a”, “c”, “d”, “k”, “o”). For example, if a trader gets different sensors and later wants to take advantage of using them together, it is not possible;
- 2) accuracy / acceptability: security in wireless transmissions must be improved in the cases where the biosignals are communicated by the wireless method. Bluetooth protocol is commonly used and has some security problems [115]. It would be desirable therefore to ensure that this data is truthful (accuracy) and protected (acceptability) to avoid security risks. Besides, if a trader uses stress measurement within a decision making process and somebody can capture and change this parameter, the trading process could be manipulated; and
- 3) acceptability: the battery life of the sensor in cases such as the scenario where the trader is in trading live (Wall Street) is crucial. It is possible to identify an important area for improvement in all the sensors that use batteries. The batteries are possibly too big in many cases. This problem is accentuated in the case of wearable sensors. Longer duration of the batteries and batteries of smaller size would be desirable.

Having considered this comparison, it is possible to identify how sensor technology can assist traders to be aware of their stress. Furthermore, we have suggested some points on how the technology can be improved to fulfil the basic principles of the biometric sensors in a trading context. However, in order to ensure the successful integration of the sensor technology in the trading process, it is necessary to establish how to adapt the information on stress levels to the trading process, otherwise the technological support integration could not be satisfactory [116]. Some aspects to consider in this integration are explained in the next subsection below.

D. Issues in trading process where sensor technology can be deciding

Our approach aims at providing assistance during the trading process by providing psychological data with the technological support offered by new sensors. For this approach, we need to know, firstly, the information that is used in the trading process, how it is possible to complement this information, when it is a suitable time to present to the trader information on her/his stress levels and finally how and what we must measure to reach an integrated trading process with the new data.

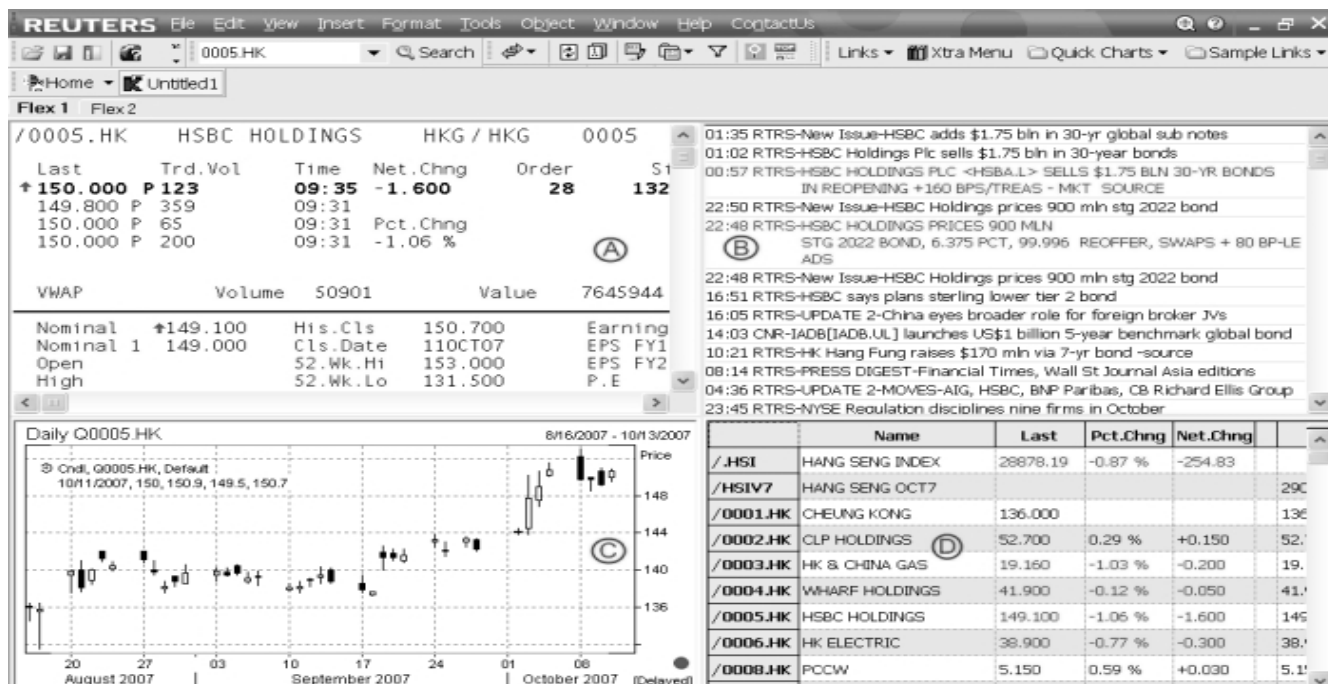


Fig.2. Reuters 3000 Xtra Trader Information

Account(s) Information

	Acct ID	Owner	Trader	Balance	Equity	UsdMrg	UsbMr	MC	OP	Comm	Pmn	NetPL	DA	Group	Curr
<input checked="" type="checkbox"/>	1514591	vtuserguide	vtus...	10000.00	9997.00	25.00	9972.00		0.1	0.00	0.00	-3.00	1	1	USD
	Total			10000.00	9997.00	25.00	9972.00		0.1	0.00	0.00	-3.00	1.0		USD

Fig.3. CMS Forex Account Information

1. Current information in trading process

Usually traders manage a significant amount of real time information which supports their decision making in real time. This information is provided by different companies under paid subscription. For example, Fig. 2 shows typical information from Reuters systems [117] where four main sections can be seen: A. Quote - Display a full quote, B. News - Provide headlines and full-text news, C. MetaStock Chart - Create graphs and technical analysis, D. Matrix - View quotes for a portfolio of instruments.

The trader should also take into account other important information: the accounts of customers. Usually traders are in charge of some clients' accounts and depending on the profile of the client (conservative, brave), the time of investment (short-term, long-term) and even the results of the trader in the session, the decisions made can differ with the same news and the same real time trading information. An example of the information on accounts is presented in Fig. 3, following the format of CMS Forex reports [118]. As both figures illustrate (Fig. 2 and Fig. 3), significant information is processed for the trader in real time.

2. *Trader's Stress: The missing information in trading*

According to [119] “the markets are not random, because they are based on human behaviour, and human behaviour, especially mass behaviour, is not random. It never has been, and it probably never will be”. This paper suggests that all of

the current information used by traders could be useless if the trader is suffering from the effects of stress (see Section III). Besides gathering and feeding back this information to the traders, they are closer to understand their behaviour, therefore the markets. At present, however, traders are not aware of this data, that is to say, his/her own stress levels and furthermore, the problem is that without sensor support, when a trader realises that his/her decisions are being made under stress, it could be too late. If we have a trader aware of his/her own stress (Stress-Aware Trader), when the sensors detect a non secure decision making moment and the alert appears in the trading information process, the decision as to how the trader can manage this information could depend on the context of the trader. However, the entry of the sensor technology allows traders to be aware of his/her state decision making and of his/her own risk.

The new sensor support in trading context can arise some questions with complex solutions. According to Weick [120] “if there is a structure that enables people to meet sudden danger, who builds and maintains it?” Probably, a possible answer depends on the context and the organization. For example, an individual trader can decide whether to stop an operation or to continue with it. If the context was an investment bank where the trader is an employee of this entity, the action could be to always stop the operation. Even an alert could be shown to the traders’ supervisor in case a team of traders’ stress level was increasing constantly a defined period

of time. In any case, a Stress-Aware Trader conducts a more secure trading process.

E. Guidelines for designers

Being self-aware of stress levels at crucial times is an important tool for a trader during the trading-process. However, this information could be harmful if it is not shown in the right way. Once the information that traders usually manage is known, it is necessary to take into consideration the following concepts: the trader's profile and how and when the stress information should be shown to her/him. Here we consider three elements: the adaptive stress time window to reach the adaptability principle, interruptions and secondary tasks to assure a complete acceptability principle.

- 1) adaptive stress time window: it may be more helpful for the trader to see the average real time stress level every five minutes rather than each second. Every person has different biometric reactions depending on several parameters. Those parameters include age, experience or the kind of trading carried out (futures, shares, commodities, etc). It is necessary to have an adaptive measure of the trader's stress depending on the trader's profile. We call this the "Adaptive stress time window". The adaptation of the time window could be offered automatically (by using learning technology), whilst preserving the possibility for manual selection;
- 2) interruptions: according to Speier et al. [121], interruptions make information overload worse by reducing the amount of time one can spend working on the problem, which in turn leads to a feeling of being under pressure. This creates both capacity interference (too much information to process), and structural interference (inputs that are occupying the same physiological channel), that is, requiring to monitor two visual displays at once. If traders are attentive to the devices or the software to manage stress level, they are adding a continuous interruption to the trading process and recovering the concentration could cost several seconds [122] thus increasing the risk. It is therefore sensible to show an alert to the trader only when it is necessary to liberate traders from interruptions. In this sense, Picard and Liu [123] built a new mobile system that interrupts the wearer to support self-monitoring of stress evaluating an empathetic version of the mobile system vs. a non-empathetic version concluding that the user does point toward a preference for the empathetic system; and
- 3) secondary tasks. Entin and Serfaty [124] placed subjects under a main task with time pressure and secondary task. The authors found that with difficult decision tasks, subjects preferred to seek additional input from the easy-to-process opinion of a consultant versus raw data from a sensor probe. This was particularly the case as time pressure and workload increased. Traders need not only know their own stress levels at the exact time; this should be also presented in an easy way (stress level) and without complicated data to analyse. This is an important concept

to apply in the model; we need to show the stress level to the trader in an easy way, thus liberating traders for secondary tasks. It may be of interest to show heart rate, skin temperature and other parameters, but they may overload the trader's attention capacity. Hence, we consider it useful to translate in the background various sensing inputs in a simple stress level indicator.

Guided by the previous considerations in this survey and our previous work research in sensor technology in trading process ([125], [126]) and in the development of a rule-based recommendation system for traders [127], some recommended guidelines respecting the basic principles described in section IV may be identified which should be considered by sensor technology designers to support traders. In Table VII some recommended guidelines are shown according to some important points to consider and a brief explanation about the importance of these points.

TABLE IV
RECOMMENDED GUIDELINES

Points to consider	Explanation / Principles affected
Real Time	The stress level should be processed and transmitted in real time, but it should not hinder the trader during trading process. / Performance, Adaptability.
Wearable	The biometric sensor should be wearable in order to be unnoticed to the trader. / Acceptability.
Networking	The sensor technology used should have standard networking capabilities in order to not only send the data to the trader, but also to have the possibility to send the data to a supervisor online (investment company) without additional effort. / Accuracy
Security	Security communications are required in order to protect the personal data of the trader. / Accuracy.
Batteries	In cases where the design is focused on wearable technology, small batteries with long life are desirable. / Acceptability.
Software	A standard interface on the software to measure the biometric levels is desirable to allow the interaction between different kinds of sensors. / Performance.
Alerts (When)	Alerts should only be shown to the trader if there is an indication that her/his stress level jeopardizes decision making. This communication should be simple to raise the awareness of the trader (such as a traffic signal); this alert should disappear when the trader's stress levels return to normal. / Adaptability.
Alerts (Where)	The alert should appear in the trading information process in real time (news, accounts, etc), in such a way that the trading process is not interrupted but the trader is made aware of her/his stress levels. / Adaptability.

V. SUMMARY OF CONTRIBUTIONS, CONCLUSIONS AND NEW DIRECTIONS

A. Summary of contributions

Complementing and supplementing existing surveys in stress effects and sensor technology: The existing studies about stress and sensor technology are focused in their specific disciplines, this paper applies these studies to the trading process since decision making is the main tool used by traders (see Section II) and provides a detailed review of these fields (see Section III) in the context of trading. Additionally, a detailed discussion is provided in Section IV about the design of the sensors currently available in the commercial market

(Table II). This discussion is based on proposed basic biometric principles in trading process (Table I) and as result of a comparison made (Table III) between the products shown with some weak points detected has been commented in order to give some recommended guidelines.

The review of some important current research projects where sensor technology is used independently is also covered within Section IV. Here it is possible to see the great development existing and the fast dissemination of this technology in our daily lives: sport, health care, work, and the trading process is not an exception.

Furthermore, this survey significantly complements and expands our previous work in this area ([125], [126], [127]). Even if we want to help traders with one automatic trading process ([8], [9], [10], [127]), we need to understand not only the technology also the psychology approach to understand how we can design systems in a right way.

Identifying basic biometric principles to take into account in sensor technology for trading process: Usually biometric sensor principles, the so-called ‘seven pillars’, are focused in identification purposes. In this survey we change slightly the focus and we propose basic principles focused in the state of the trader. These principles are used to compare the existing available sensors in the market and give us the clue of what we need to assess a successful integration of the sensor support in the trading process.

Identifying issues in the trading process where sensor technology can be decisive: Whereas [57] and [90] show the connection between the emotions of the traders and the movement of the financial market with sensor technology, this work identifies the potentially crucial role of sensor technology in the trading process. Sensor technology could be used to enable traders to become aware of their stress levels when making decisions, thus covering this current information gap. In this way, sensor technology becomes an active element in the trading process.

Guidelines for designers: Another contribution of this survey is the identification of some common needs that are desirable for the successful integration of sensor technology in the trading process. It does so by explicitly highlighting some papers ([121], [122], [123], [124]) in Section IV about the importance of how sensors should show the relevant data to traders and in this context, the parameters that should be adapted (manually or automatically) to the trader’s profile preference (stress time window). The purpose of the discussion about Table III in this survey is to consider some characteristics to obtain the most suitable sensing infrastructure for the trading progress giving some recommended guidelines based on basic principles for biometric sensor applied for designers in Table IV.

B. Conclusions and new directions

Studies on stress clearly illustrate that this mental state can have a significant impact on our daily life. However, there is little done on how to detect it timely. Most efforts are focused on managing its consequences. Trading is a clear example where people can benefit enormously by managing the problem before it appears (avoiding bad decision making) instead of trying to manage the consequences (dealing with

bankruptcy and ill health). Fortunately, current technology offers new opportunities to tackle this issue.

This paper refers to a variety of ways by which sensor technology can detect biometric changes in real time. This technology allows the traders to be aware of their own stress levels, thus facilitating, with this new information, improved decision making in the trading process. However, this is only one part of the solution. The precise method used by the support systems to bring to the attention of the trader that he/she is in a state of stress is as important as the actual detection of stress. Psychological aspects must be considered along with technical aspects respecting biometric basic principles according to trading. The technological solution should be non invasive and wearable so that it does not distract the trader unnecessarily.

Furthermore, the biometric changes alerts should be shown in the right way (only when strictly necessary and integrated in the trading information process). In addition, the stress level measurements should remain flexible according to the trader’s profile and needs (stress time window).

There is a fine line between offering information and causing more stress. During the trading process, traders have real time information from the markets, advice from experts systems suggesting specific operations, and a variety of other data to help them in the decision making process. One of the most fundamental pieces of information traders usually do not have is an objective measure of their own mental state and stress levels. Stress-Aware Traders will be better positioned to appropriately handle difficult decisions appropriately at key stages of their trading.

C. Concluding remarks

Research referred to in this paper is based on three different established areas: stress effects in decision making (Section II), biological stress parameters (Section III) or sensor technology (Section IV). This survey merges these disciplines and proposes new possibilities for applications for sensor technology in the trading process.

This paper suggests that a Stress-Aware Trader should consider stress as an important parameter of the decision making process. This specific data, currently missing from common practice, could be the most important information because during stressful moments, all useful information that traders manage in their daily work may not be correctly processed. If we extend the Stress-Aware Trader concept to a group of traders, we could create Group-Aware information as being highly valuable information for different uses (supervisors managing an investment company, detecting panic moments in the market, etc).

It is hoped that this survey will provide the foundation for understanding the important role than sensors have in the trading process. Furthermore, it is hoped that it will inspire other researchers to take up the challenge to investigate some of the issues raised in this article as combinations from different disciplines such as trading (economy), stress (medical) and sensors (technological).

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